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1 **Social interaction and pain: An arctic expedition**

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1 **Social interaction and pain: An arctic expedition**

3 **Abstract**

4 Complex human behaviour can only be understood within its social environment.
5 However, disentangling the causal links between individual outcomes and social network
6 position is empirically challenging. We present a research design in a closed real-world
7 setting with high-resolution temporal data to understand this interplay within a fundamental
8 human experience – physical pain. Study participants completed an isolated 3-week hiking
9 expedition in the Arctic Circle during which they were subject to the same variation in
10 environmental conditions and only interacted amongst themselves. Adolescents provided
11 daily ratings of pain and social interaction partners. Using longitudinal network models, we
12 analyze the interplay between social network position and the experience of pain.
13 Specifically, we test whether experiencing pain is linked to decreasing popularity (increasing
14 isolation), whether adolescents prefer to interact with others experiencing similar pain
15 (homophily), and whether participants are increasingly likely to report similar pain as their
16 interaction partners (contagion). We find that reporting pain is associated with decreasing
17 popularity – interestingly, this effect holds for males only. Further exploratory analyses
18 suggest this is at least partly driven by males withdrawing from contact with females when in
19 pain, enhancing our understanding of pain and masculinity. Contrary to recent experimental
20 and clinical studies, we found no evidence of pain homophily or contagion in the expedition
21 group.

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Keywords

Stochastic actor-oriented models, social networks, pain, adolescence, social influence, sex differences.

Introduction

Human traits, behaviors, and experiences are tightly linked to the structure of interpersonal interaction that spans social networks; neither one can be fully understood without reference to the other (Rivera, Soderstrom, & Uzzi, 2010). Accordingly, investigating the causal relationship between individual outcomes and embeddedness in social networks is an important, yet empirically difficult endeavour (Shalizi & Thomas, 2011). We present here a study design that explicitly and directly investigates longitudinal, bidirectional interactions between network position (the number and types of connected others) and a fundamental experience that drives much of human behaviour – physical pain.

Pain is a fundamental motivator of behaviour, serving to protect the body and ultimately promote lifespan. The study of pain in the psychosocial context appears especially interesting and promising, as the human experience of pain is now widely recognised to be situated within and shaped by the social world (Craig, 2009), making it a pertinent field for psychological enquiry. Past research on the association between pain and social relations has shown that higher pain tolerance is correlated with larger self-reported social group size (Johnson & Dunbar, 2016), and that chronic pain is linked to poorer relationships and self-imposed isolation (Smith & Osborn, 2007; Snelling, 1994). Experimentally-induced social exclusion and perceived social support respectively increase and reduce the severity of acute experimental pain (Brown, 2003; Eisenberger, Jarcho, Lieberman, & Naliboff, 2006; Master

1 et al., 2009). Evidence suggests that, like depression (Schaefer et al., 2011), obesity
2 (Cunningham et al., 2012), and numerous health-related behaviours (Steglich et al., 2010),
3 pain may have the capacity to be socially transmitted (Martin et al., 2015). Also emerging is a
4 role for sex, gender, and perceptions of masculinity/femininity, with these factors appearing
5 to influence interactions between pain and social context (Keogh, 2006).

6 However, major questions remain. Current studies on the interactions between pain, sex,
7 and social factors are limited, with most studies relying on reports from individual
8 participants, dyadic interactions at single time-points, or experimentally induced pain. Little
9 is known about reciprocal relations between naturally occurring pain and social networks
10 over time. In this study, we analyse fine-grained, voluntary interactions between adolescents
11 and their interdependence with naturally occurring pain in an observational study.
12 Participants completing a 3-week hiking expedition in the Arctic Circle provided daily reports
13 of interaction with others and ratings of pain. In this context, we focus specifically on (i) how
14 the experience of pain is related to social integration and tie formation (pain popularity, pain
15 homophily), and (ii) whether pain is “contagious”, that is, whether interacting with others in
16 pain increases the likelihood of reporting similar pain experiences.

17

18 *Pain and social integration*

19 Empirical research suggests that chronic and recurrent pain in adults and adolescents
20 negatively affects social relationships. For example, regularly experiencing pain is linked to
21 having fewer friends, worse peer relationship quality, victimisation, and social problems
22 within the family unit (see Forgeron et al., 2010 for a systematic review; Smith & Osborn,
23 2007; Forgeron et al. 2011, 2013; Lewandowski et al. 2007; Snelling 1994). Among the main
24 mechanisms thought to underlie this relation in adolescents is the decreased likelihood of

1 interacting with peers when in pain (Forgeron et al. 2010). Pain hinders the ability to take
2 part in social activities and interactions as well as decreases the willingness to interact, with
3 self-isolation being a negative coping mechanism for pain. At the same time, others might
4 withdraw from interaction with adolescents in pain, as they are seen as less likable and less
5 fun to spend time with (Forgeron et al. 2010).

6 However, the relation between experiencing acute pain and interaction frequency is likely
7 to vary with sex (Keogh, 2006; Keogh, 2009; Keogh, 2012). Females and males tend to differ
8 in their coping strategies for pain, with females being more likely to seek social support and
9 share their experiences than males (Keogh, 2006; Bartley and Finnigan, 2013). Relatedly,
10 cultural beliefs about masculinity and femininity influence the perception and social
11 acceptability of expressing pain across gender (*ibid.*). For example, a recent study found sex
12 differences in the encoding of pain-communicative body postures (Walsh, Eccleston, &
13 Keogh, 2017). These perceptual differences, in turn, are likely to affect how males and
14 females in pain are treated by others (Keogh, 2006). Another study found that males' pain
15 tolerance increased only when in the presence of male, but not female, friends, which the
16 authors speculate may be driven by cultural beliefs regarding competitiveness and the male
17 prerogative to tolerate pain (Edwards, Eccleston, & Keogh, 2017; Walsh, Eccleston & Keogh,
18 2017). In the context of our study, this leads us to hypothesise that being in pain will lead to
19 decreased interaction with other expedition participants. This relation should be especially
20 strong for boys.

21

22 *Social contagion of pain*

23 Recent experimental evidence suggests that pain may have the capacity to be socially
24 transmitted (Martin et al., 2015). In this experimental study, participants reported increased

1 pain intensity when they observed a familiar other experiencing the same type of pain. The
2 hypothesised mechanism for this finding is based on empathy. Empathy is the capability to
3 understand the personal experience of another person, often coupled with affective
4 responses (Goubert et al., 2005). In the context of empathy for pain, it has been shown that
5 observing another person in pain elicits similar neuronal responses as if the observer were
6 experiencing this pain themselves (Singer et al., 2004), providing a neuronal basis for
7 empathy.

8 Further, past research suggests that women tend to empathise more than men do (Han et
9 al., 2008), and that women are more expressive of their pain (Walsh et al. 2017). In the
10 context of our study, this leads us to hypothesise that interacting with a peer reporting a
11 particular type of pain leads to a heightened probability of reporting the same type of pain.
12 In light of previously found sex differences in empathy and pain communication, we believe
13 this relation will be especially strong for girls.

14 As we elaborate in the next section, a common confounder in observational studies on
15 social influence is homophily, the tendency of people to have ties to similar others. While we
16 are not aware of studies that specifically analyse pain-homophily, similarity-attraction theory
17 predicts that people seek out contact with others that have common experiences
18 (McPherson et al. 2001). Similarity is presumed to lead to facilitation of communication and
19 improved understanding of similar others. Homophily on distressing experiences has
20 previously been analysed, for example, on negative affect (Schaefer et al. 2011) or
21 victimisation from bullies (Lodder et al. 2015). Thus, we hypothesise that adolescents in our
22 study tend to seek contact with others who experience similar levels and/or types of pain.

23

1 *Research design*

2 Research using observational data on the relation between pain and network position
3 faces difficult empirical challenges, known from network studies in other domains (Christakis
4 & Fowler, 2007; Cohen-Cole & Fletcher, 2008; Lyons, 2011). Disentangling cause and effect,
5 that is whether network position predicts individual attributes or *vice versa*, is not trivial, as
6 multiple psychosocial mechanisms can lead to the same cross-sectional outcome (Shalizi &
7 Thomas, 2011; Steglich, Snijders, & Pearson, 2010). Connected individuals suffering from
8 similar types or intensity of pain could be a result of social transmission of pain (contagion),
9 but also of selecting interaction partners that were already similar in the first place
10 (homophily). Likewise, the association of social isolation and pain might be explained by
11 ostracism of individuals in pain (decreasing popularity), as well as by social isolation leading
12 to more intense pain experiences (Smith & Osborn, 2007). Additionally, unmeasured
13 heterogeneous exogenous causes can lead to similar network patterns. In this case, common
14 experiences lead, at the same time, to being socially connected and experiencing pain; for
15 example, living in the same neighbourhood can lead to being socially connected as well as
16 being subject to the same environmental stressors, such as pollution or noise.

17 Consequently, studies on the relation between networks and individual outcomes require
18 longitudinal data in conjunction with multivariate statistical models that simultaneously
19 model network evolution and changes in individual outcomes to distinguish cause and
20 effect. Equally, tendencies of networks to evolve endogenously, such as reciprocity or
21 clustering/transitivity need to be taken into account (Shalizi & Thomas, 2011; Steglich et al.,
22 2010). At the same time, data collection should ensure that heterogeneous environmental
23 influences are absent, i.e. that all study participants are exposed to the same exogenous
24 factors that can influence the dependent variable.

1 We present here a study design that explicitly addresses these difficult requirements to
2 investigate longitudinal, bidirectional interactions between pain and social network position,
3 leveraging promising tools from social network analysis (Snijders, van de Bunt, & Steglich,
4 2010). Stochastic actor-oriented models (SAOMs) allow the simultaneous analysis of the
5 evolution of networks, as well as change in actor attributes; for example, changes in social
6 interactions in a group of individuals, changes in their experiences of pain, and the
7 temporally contingent relation of these observations. The SAOM continuous time approach
8 enables disentangling of different network mechanisms that result in the same cross-
9 sectional outcome: namely, selection versus influence.

10 In this study, we combine this method with temporally high-resolution data in an isolated
11 but real-world setting. Late adolescents participating in a physically demanding, three-week
12 hiking expedition in Greenland's Arctic Circle reported daily on their social interactions and
13 pain experiences. Participants were exposed to the same environmental factors each day
14 and interacted only with other members of the expedition group, allowing tight statistical
15 control for potentially confounding heterogeneous influences. We analyze how reported
16 pain and social connectedness are linked, and whether similarity of pain experienced by
17 connected interaction partners is based on pain homophily or contagion.

18 We tested three hypotheses: 1) individuals report fewer interactions with peers who
19 experience more pain (pain popularity); 2) individuals interact with peers who experience
20 similar pain (pain homophily); 3) individuals become more similar to their peers in terms of
21 pain (pain contagion). Given the moderating influence of sex on diverse pain experiences, we
22 examined sex effects on each hypothesis.

23

1 **Materials and Methods**

2 *Participants*

3 Participants were recruited from an academically selective coeducational state secondary
4 school in South East England. All participants had registered for a 3-week hiking expedition
5 in the Arctic Circle, Greenland. The expedition was organized by the school, and students
6 had registered for the expedition before they were contacted about taking part in the
7 current study. Nineteen participants from a single year group (grade level) had registered for
8 the expedition and 17 (8 female; mean age 17 years) participated in the study. Participants
9 reported being acquainted with network members for a mean duration of 5.86 (SEM 6.14)
10 years, with range 0-17 years, before the start of the expedition. Participants gave informed
11 consent to take part. Data were collected during July and August 2015. The study was
12 approved by the University of Oxford Central University Research Ethics Committee.

13 *Materials*

14 *Daily Pain Log.* Each day participants reported their experience of seven different types of
15 pain using a pain site checklist (Jensen, Hoffman & Cardenas, 2005): 1) Pain due to the cold,
16 2) Pain due to muscle use, 3) Headache, 4) Pain due to rubbing/blisters, 5) Pain from injuries,
17 6) Stomach ache, 7) Other pain. Pain types were chosen according to the general prevalence
18 of pain (Moore *at al.*, 2013) as well as pain types judged to be especially relevant to the
19 expedition. For each pain type the two main dimensions of pain, pain intensity and pain
20 unpleasantness (Jensen & Karoly, 2011), were recorded on a numerical rating scale (NRS)
21 from 0 to 10 (0 = no pain; 10 = worst possible pain and 0 = not at all unpleasant; 10 =
22 extremely unpleasant). Validity of these measures is well documented (*ibid.*). Additionally,
23 participants reported on pain frequency (0 = never; 10 = all day) for each type of pain. There
24 was no missing data for the daily pain logs.

1 *Daily Interactions Diary*. Participants reported each day on their interactions with other
2 members of the expedition team. These interactions reflect individuals' choices with whom
3 to spend time. Participants were required to report the four persons with whom they spent
4 the most time. Data were elicited using a questionnaire in which the number of nominated
5 interaction partners is fixed, as the total time spent in the group, and thus the opportunity
6 for interaction was constant across all participants. Participants also rated how enjoyable
7 they found each interaction (0 = extremely un-enjoyable; 5 = extremely enjoyable).
8 Participants were instructed to only report on interactions with members of the team who
9 were also participating in the study, therefore excluding the two students who did not take
10 part, and the five adult expedition leaders. Two participants did not provide interaction data
11 for one day each resulting in 0.6% missing data and 58 nominations were to expedition
12 leaders or students not taking part, i.e. 4% invalid data recoded as missing.

13 *Procedure*

14 Participants woke between 7-8am each day and ate breakfast together. On most days
15 they hiked for around 7 hours, arrived at a new campsite location around 4pm, ate dinner
16 and rested. On two days during the expedition participants completed only a small hike and
17 rested for the majority of the day. On the last two days participants were travelling back to a
18 nearby city and resting; these days are excluded from inferential analysis. At the end of each
19 day participants completed the Daily Pain Log and Daily Interactions Diary in private. As
20 participants needed to carry their belongings on the hike each day, and had no access to the
21 Internet, the measures were printed on A5 pieces of paper. Papers were combined into
22 booklets and carried in waterproof document pouches. Each participant carried his/her own
23 document pouch for the entire expedition.

1 *Data analysis plan*

2 Analysis proceeded via three steps: First, a general description of the networks; second,
3 an analysis of descriptive statistics related to the outlined hypotheses; and third, statistical
4 modelling of the data using SAOMs. In the descriptive analyses, the detailed pain ratings on
5 the numerical rating scale were used. In the inferential analysis these measures were
6 dichotomised, as outlined further in the relevant section. All analyses were conducted using
7 the statistical software R. Network plots were created using the library “igraph”; SAOMs
8 were estimated with the library “RSiena” version 1.1-289 (Ripley at al. 2017). For both
9 descriptive and inferential analyses, main results were obtained using daily reported pain
10 intensity (analyses using pain unpleasantness and frequency are reported in the
11 Supplementary Information). Further, only interactions rated as at least slightly enjoyable
12 were included in the analysis, which comprised 98% of all measured interactions.

13

14 *Descriptive Analysis*

15 The descriptive analysis comprised of 1) visual inspection of the interaction networks, 2)
16 scatter-plots assessing the relation between pain intensity and nominations received
17 (separately for males and females), and 3) descriptive analysis of pain intensity homogeneity
18 among network members. The first analysis is self-explanatory. For the second analysis, pain
19 intensity for all measured pain variables was summed and plotted against the number of
20 nominations received. We focus on the number of nominations received, i.e. popularity, to
21 assess connectivity in this and all subsequent analyses, as the number of nominations sent is
22 constant across all participants, due to our data collection strategy. The third analysis
23 exploring pain homogeneity requires additional explanation, which is given below. For all
24 descriptive analyses the use of standard tools to calculate confidence intervals was avoided,

1 as the assumption of independent observations is violated for network data.

2 To descriptively assess similarity between interaction partners in terms of pain intensity, a
3 network-based measure of pain homogeneity is proposed. This is defined as the sum of pain
4 homogeneity of all connected pairs of individuals (in network research commonly denoted
5 as actors) in the network. Pain homogeneity between two connected individuals is the sum
6 of the minimum intensity of pain both interaction partners felt jointly for each type of pain.
7 Formally, the network pain homogeneity h is defined as

$$h = \sum_{i,j} x_{ij} \sum_k \min(z_{i,k}, z_{j,k}),$$

8 where x_{ij} is the tie variable between actors i and j which equals 1 if they interact and 0
9 otherwise, k is the index running over all pain items, and $z_{i,k}$ is the amount of pain actor i
10 felt on pain item k . As the network level score of h depends not only on pain homogeneity
11 between actors, but also on overall pain intensity reported on a certain day and the specific
12 network structure, the observed value of pain homogeneity was compared to a distribution
13 of the expected value of pain homogeneity if individual pain experience were independent
14 of the pain experience of interaction partners. This expected null distribution was calculated
15 using permutations, leaving the network structure intact but randomly reassigning observed
16 pain levels across individuals.

17 *The Stochastic Actor-Oriented Model*

18 Stochastic Actor-Oriented Models (SAOMs, Snijders et al., 2010) model the evolution of a
19 network or the co-evolution of multiple networks and/or attributes of network actors over
20 time. While data are recorded as panel data at discrete time-points, the model assumes
21 changes happen in continuous time between the observations. Changes are modelled as a
22 series of *mini-steps* comprising a change in a single tie variable or attribute of a single actor.

1 Multiple *mini-steps* connect the observations at discrete time-points, while the exact
2 ordering of the (unobserved) *mini-steps* is varied using simulations. The *mini-step* lies at the
3 heart of the SAOM, as here hypotheses are tested by formalising them as parameters that
4 influence how actors in the model chose their interaction partners or change their
5 experience of pain. For further details of SAOMs, see (Snijders et al., 2010; Steglich et al.,
6 2010).

7 In the reported model, technically the co-evolution of two networks over 18 consecutive
8 periods is analysed (see Stadtfeld, Mascia, Pallotti, & Lomi, 2016). The first network depicts
9 the interactions between participants as outlined above. In the second network, participants
10 technically form “ties” to different types of pain. A “tie” to a type of pain exists where the
11 participant reports experiencing this pain equal to or more intensely than a threshold (in
12 these analyses a threshold of 2 was used for the pain scales; robustness to other thresholds
13 is checked). This transformed projection of data is called a bipartite network. While
14 dichotomising the pain variables results in some loss of information, modelling pain as a
15 bipartite network is much closer to our theoretical argument outlined in the introduction, as
16 elaborated below.

17 In the model in each *mini-step* an actor can, when it comes to changing the pain
18 experiences, create a new “tie”, i.e. report a new type of pain, or delete an existing “tie”, i.e.
19 report that a pain previously experienced is now absent. These changes in reporting pain
20 depend, among others, on whether their interaction partners have a “tie” to this type of
21 pain. Thus, it allows modelling whether the actors start feeling the same type of pain that
22 their friends feel, that is, influence in pain experience (contagion hypothesis).

23 At the same time, if actors changes ties in the interaction network, they can stop or start
24 to interact with any other actor in the network. This depends, among other factors, on how

1 many types of pain the potential interaction partner reports and how many pain types ego
2 and alter share. These statistics relate to the hypothesis on pain popularity and on pain
3 homophily, respectively.

4 The strength of using the bipartite network is of theoretical and technical nature –
5 empathy is assumed to work on the same dimension of pain. Interacting with someone that
6 has a headache is proposed to influence the probability to report a headache, but not
7 another type of pain, such as pain from cold. At the same time, coding all pain intensity
8 variables into one bipartite network increases the statistical power, as it allows estimating
9 one overall influence parameter (and homophily / popularity parameter) rather than an
10 influence parameter for each type of pain, or an influence parameter on one overall pain
11 measure.

12 Technically, influence is modelled as the closure of a triangle when actor i starts to report
13 pain item k if the connected interaction partner actor j reports pain item k . The tendency of
14 girls to be differentially influenced by peer pain is modelled by an interaction of the above-
15 mentioned parameter and the sex of the focal actor i . Pain popularity is modelled as forming
16 a relation from actor i to actor j , based on the number of pain items k actor j reports. Pain
17 homophily is modelled as actor i forming a tie to actor j based on the number of pain item k
18 both have in common. The differential effect of pain on popularity in boys and girls is
19 modelled by an interaction between the mentioned parameter and the sex of the receiving
20 actor j .

21 In both the pain and network evolution parts of the model a number of control
22 parameters were included. For pain evolution, it is modelled whether girls tend to report
23 more pain types than boys, and whether some individuals show an inherent tendency to
24 report more pain (outdegree Activity). Further, the propensity to experience different types

1 of pain is modelled using dummy variables for each type of pain (with pain from cold as the
2 arbitrary reference category); 18 additional dummy variables are included for each day of
3 the hike to control for differential strenuousness of each day. For network evolution, the
4 tendency of interactions to be mutual and to cluster in groups, as well as their statistical
5 interaction, i.e. testing whether mutuality is more or less prevalent in social groups, is
6 modelled as a control. Further, sex differences in popularity and sex homophily (that is, a
7 preference to interact with same-sex peers) are included in the analysis.

8 For further explanation of the SAOM and details of the estimation routine and algorithms,
9 see Supplementary Information.

10

11 **Results**

12 Initial description of the data shows that the network tends to be relatively stable over the
13 course of the expedition, with an average turn-over of one third of the ties each day. The
14 experience of pain had large variation within, as well as between, individuals. There was
15 large variation in intensity across different types of pain (see Supplementary Information).

16

17 *Descriptive Analysis*

18 Figure 1 shows the social interaction network at four time-points five days apart, with
19 each individual's intensity and type of pain. The plots show that some adolescents tend to be
20 in more pain over the entire course of the expedition, e.g. the two nodes towards the lower
21 right of the network are larger and deeper red than the average node. However, it is difficult
22 to discern from visual inspection alone whether adolescents in pain are relatively less
23 connected, or whether connected adolescents tend to report similar levels of pain.

1 Descriptive statistics related to the hypotheses explore (i) the relation between
2 experiencing pain and being nominated as an interaction partner for males and females, and
3 (ii) the amount of homogeneity in pain experience between interaction partners for males
4 and females. Figure 2 shows a scatterplot representing the relationship between
5 experiencing pain and being nominated as an interaction partner, separately for males and
6 females (popularity hypothesis). The popularity of females seems unaffected by the amount
7 (intensity) of pain they report. For males, this was not the case; the more pain males
8 experienced, the fewer nominations they received.

9 Figure 3 visualises whether connected pairs of participants experienced similar levels and
10 types of pain, compared to a null-distribution created under the assumption that network
11 position and pain experience are independent. This is related to the hypotheses on pain
12 homophily and contagion, both of which should result in connected adolescents being more
13 similar than random pairs in the network. The grey shaded area shows the 50% and 90%
14 confidence band of expected observations were pain and interaction independent, with
15 changes in the null distribution across days resulting from differences in pain experiences
16 over the course of the expedition (see SI); the red line shows the empirically observed value.
17 The plots suggest there is no systematic deviation from the null-distribution. Additional
18 analyses (see Figure S2 in the SI) show that pain homogeneity equally does not exceed the
19 expectation under the null hypothesis when looking only at same sex interaction pairs.
20 Hence, there is no descriptive evidence that either pain homophily or pain contagion are
21 present in the data – neither for males, nor for females, nor for the entire network.

22

23 *Statistical Analysis using SAOMs*

24 The results of the analysis using SAOMs reveal tendencies according to which individuals

1 change their social interactions and individual attributes. Since both types of changes are
2 modelled simultaneously in continuous time, SAOMs permit dissociation of selection from
3 influence processes. Using SAOMs, hypotheses outlined in the introduction regarding pain
4 popularity and pain homophily were tested by including them as terms in the network
5 evolution part of the model that represent whether participants tended to report being
6 more or less connected to others who are in more pain, or who experienced similar amounts
7 of pain, respectively. The third hypothesis (pain contagion) was tested in the pain evolution
8 part, modelling whether adolescents tend to experience specific types of pain if their
9 interaction partners do so.

10 Table 1 shows the results of the SAOM analyses. Three models were estimated. In the
11 first model, the effects related to the basic hypotheses (pain popularity, pain homophily, and
12 pain contagion) are included. The second model analyses whether there are differences in
13 pain popularity and pain contagion between males and females. The third and final model is
14 exploratory in nature and further analyses the patterns found in the previous models that
15 relate to a decreased popularity of males in pain. Model 1 shows no evidence that
16 adolescents nominate as interaction partners others that report similar types of pain, as the
17 Pain Homophily parameter is small and the confidence interval includes zero. At the same
18 time, there is no evidence that interacting with others who report certain types of pain leads
19 to participants reporting more of the same type of pain, as shown in the small and non-
20 significant Pain Contagion estimates. Thus, we find no evidence that support the hypotheses
21 on pain homophily or pain contagion, in line with the descriptive analyses in the previous
22 section. However, we see that adolescents who report more types of pain are less popular as
23 interaction partners, as the negative, significant Pain Popularity parameter shows. This
24 supports the hypothesis on pain popularity.

1 As the descriptive statistics in Figure 2 suggest, this decreased popularity might not hold
2 equally for males and females, which is tested in Model 2. Indeed, the interaction Pain
3 Popularity * Male is negative and significant. At the same time, the size of the main effect
4 diminishes and becomes non-significant. Thus, males in pain are less attractive as interaction
5 partners, while there is no effect for females. Model 2 further analyses whether the pain
6 contagion parameter might differ between males and females. However, the included Pain
7 Contagion * Female interaction is comparably small and non-significant. Thus, we find no
8 evidence for pain contagion, neither between all connected peers, nor between peers of the
9 same sex.

10 Finally, Model 3 explores the relationship between nomination patterns and sex beyond
11 our initial hypotheses. The questions explored are whether males in pain are unpopular
12 especially among males (parameter Males Nominate Males in Pain) and whether males in
13 pain change their levels of interaction with females (parameter Males in Pain Nominate
14 Females). While the former interaction is statistically not distinguishable from zero, males in
15 pain seem to withdraw from interactions with females, as the significant negative parameter
16 suggests. Additional descriptive analyses confirm this finding, as shown in Figure 4. Males
17 who report more pain nominate considerably fewer female interaction partners.

18 The further model parameters give interesting insights into the evolution of the
19 interaction network over time, as well as predictors of pain experience. Nomination of
20 interaction partners generally tends to be mutual (Reciprocity), between adolescents of the
21 Same Sex, and embedded in a mutual interaction with a third participant (Transitivity). The
22 exact operationalization of transitivity takes the form of *geometrically weighted edgewise*
23 *shared partners* (GWESP), meaning that there are decreasing returns of an interaction tie to
24 be embedded in multiple triangles. As elaborated in the literature (Block, 2015), the negative

1 Reciprocity * Transitivity interaction indicates that the importance of reciprocity is higher
2 outside than within groups. Finally, there is no large dispersion in the number of
3 nominations received, as indicated by the negative Indegree Popularity parameter. The
4 model related to the pain evolution shows that females are more likely to report being in
5 pain than males (Effect from Sex). Further, there is a strong spread in how much pain
6 individuals report (Outdegree Activity). Finally, different types of pain have different
7 probabilities to be experienced as shown in the six dummy effects for the different pain
8 types. An additional 36 rate-variables modelling the amount of change of the network and
9 changes in pain were included, as well as 18 fixed effects modelling the strenuousness of
10 each hiking day, to control for potentially confounding environmental effects across time,
11 not shown in Table 1.

12 Additional analyses were conducted using the overall level of pain intensity participants
13 experienced, as well as analyses using pain unpleasantness and frequency to construct the
14 dependent variable; all of which led to the same findings (see Supplementary Material).
15 Further models testing whether social exclusion causes stronger pain experience, i.e. the
16 causal inverse to the pain popularity hypothesis, found no substantive results.

17

18 **Discussion**

19 We investigated the dynamic interplay between pain and social interactions, addressing
20 previous methodological difficulties by using longitudinal, temporally high resolution data
21 elicited in an isolated, real-world setting and analysed using stochastic actor-oriented
22 models (SAOMs). By doing so we disentangle pain-related popularity, homophily, and
23 contagion, and their interaction with sex for our sample of 17 adolescents participating in an
24 expedition in extreme environmental conditions. Results show no evidence of pain

1 homophily or pain contagion. We found that participants – specifically, males – who
2 reported more pain received successively fewer nominations as interaction partners, while
3 also nominating fewer females. The network position of females, in contrast, was unaffected
4 by their pain experiences.

5 Our finding that increased pain can be detrimental for social interactions is consistent
6 with previous findings in clinical samples (Forgeron et al., 2010; Smith & Osborn, 2007;
7 Snelling, 1994), as well as evidence that pain experiences can impede peer interactions in
8 adolescence specifically (Forgeron et al., 2010). Indeed, during adolescence, peer
9 relationships become critically important as time spent with family members diminishes (De
10 Lorme, Bell, & Sisk, 2013; Nelson, Leibenluft, McClure, & Pine, 2005). However, few studies
11 investigate the moderating role of sex in the interplay between pain and peer interactions in
12 youth. Our study adds to this new area of research suggesting that peer interactions may be
13 differentially affected for adolescent males and females in pain. Given that pain is common
14 in childhood, with around 25% of young people experiencing chronic or recurrent pain
15 (Perquin et al., 2000), and a significant minority experiencing severe, disabling, and
16 distressing pain (King et al., 2011), a greater understanding of the individual and social
17 factors associated with pain in youth is a pressing issue.

18 The findings in our sample of decreased popularity of males, but not females, reporting
19 pain is consistent with existing evidence that sex and gender play important roles in pain and
20 pain behavior (Bartley & Fillingim, 2013; Keogh, 2006). Specifically, male sex is typically
21 associated with reporting less pain in experimental and clinical studies (Bartley & Fillingim,
22 2013; Keogh, 2006), which might be at least partially explained by gender role expectations,
23 with masculinity being linked to a stoic characteristic, whereas femininity is perceived as
24 more sensitive (Keogh, 2009). While the literature on sex differences in pain has been rather

1 separate from studies on social experiences in clinical populations, the current study
2 examines sex differences within the broader social context. Of particular relevance to
3 understand our findings is the literature on masculinity and pain, which suggests that poor
4 health, including increased pain, can be perceived as a threat to masculinity (Keogh, 2006).
5 Recent experimental evidence indeed supports that males are more likely to tolerate pain
6 when in the presence of a male, but not female, friend (Boerner, Eccleston, & Keogh, 2017).
7 Evidence of experiencing pain may thus be less appealing in a male social partner, leading to
8 receiving fewer nominations. The finding that males in pain nominated fewer females as
9 interaction partners equally points towards pain threatening masculinity. This signposts
10 hypotheses to test regarding psychological correlates of observed inter-individual effects.
11 However, other explanations for the decreased popularity of males are possible. As outlined
12 in the introduction, different coping strategies by sex could explain the found sex
13 differences. For example, experimental studies in healthy adults have found that, in the
14 short term, focusing on pain may be of benefit to men but not to women (see Keogh, 2006),
15 and thus males might focus more on the pain and on themselves when in pain, leading to
16 less intense social contact. Regarding the observed lack of impact of pain on and by female
17 social interactions, there is also speculation that female peers may be more likely to focus on
18 and prioritise social support and intimacy, and thus be less inhibited to express signals
19 associated with pain (Reis, Senchak, & Solomon, 1985; Edwards, Eccleston, & Keogh, 2017).

20 Our research design addresses a number of difficult methodological issues in
21 disentangling individual from social factors, and may provide a frame for investigating other
22 topics where similar issues arise. The role of social interactions during group-based inpatient
23 rehabilitation programs for chronic pain invites a similar design. In different domains,
24 influence processes in, e.g., affect or health-related behaviors, could be analyzed in isolated

1 groups, such as hiking expeditions. Combining such data with SAOMs promises to gain
2 detailed insight into processes of social selection and social influence in bounded networks,
3 especially given that numerous studies claim to have found social influence on diverse
4 outcomes such as smoking, drinking, depression, obesity, cultural consumption, and even
5 loneliness. However, control of environmental influences in these studies is often necessarily
6 limited, largely due to individuals' embedding in larger communities and data collection
7 occurring several months or years apart. In this light, our null findings regarding effects of
8 pain homophily and contagion are themselves interesting. This is especially true given that
9 studies of pain contagion have only recently started emerging, but came to other
10 conclusions (Martin et al., 2015), indicating that these effects may only emerge under
11 certain conditions. Our approach also provides an excellent setting for examining
12 fluctuations in naturally occurring pain. An expedition in the Arctic Circle is both physically
13 strenuous and subject to extreme fluctuations in the natural elements, generating pain in
14 expedition participants that is varied in type and intensity.

15 The current study has limitations. First, whilst sex differences were a focus of the current
16 study, gender may also be relevant, especially given the plausible role of masculinity in
17 partly explaining our effects (Keogh, 2006). Future studies should measure self-identified
18 gender roles and perceptions of masculinity and femininity as well as sex. Second, our
19 participant sample is small ($N=17$), limiting generalizability to a wider population. However,
20 the observation sample is of considerable size with each participant rating 7 pain items and
21 nominating 4 contacts over 21 days, resulting in substantial statistical power. For the
22 purpose of this article, the limitations of a small participant sample are secondary to the
23 benefits of obtaining intricate longitudinal data within a tightly-controlled environment.
24 Nevertheless, the experience of previously acquainted, healthy, late adolescents in an

1 extreme environment might not generalize to other populations. Our findings on popularity
2 may apply particularly to evolving interactions between acquainted individuals. Third, the
3 current measures do not fully enable us to disentangle whether the causes of reduced
4 popularity of males in pain are active 'social rejection' or self-imposed 'withdrawal'. The
5 latter explanation would suggest that males who report more pain withdraw from social
6 interactions, perhaps because their increased pain leads to low mood, or threat to male
7 identity (Jackson, Iezzi, Chen, Ebnet, & Eglitis, 2005). This could make them less inclined to
8 seek social interaction (with females), which, in turn, would result in fewer received
9 nominations. Further studies combining social network methods with the study of intra-
10 individual psychological mechanisms are needed to shed light on these outstanding
11 questions.

12 In sum, our study demonstrates that it is possible to overcome common problems with
13 research on the interaction between individual and social processes, and provides rigorous
14 insight into the relation of acute pain and social interaction.

15

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24

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16

17

1 **Figure Captions**

2 **Figure 1: The interactions network at four time points**

3 Arrows between nodes indicate directed nominations as interaction partners; Node layout
4 includes information on different types of pain: Node size: Intensity of pain from muscle use
5 (larger = more pain); Node color: Intensity of pain from cold (deeper red = more pain); Node
6 shape: Intensity of pain from blisters (square = pain intensity > 3); Node frame: Intensity of
7 other pain (deeper red = more pain).

8

9 **Figure 2: Nominations received by total amount of pain experienced**

10 Popularity of participants dependent on the overall amount of pain experienced in one day,
11 measured by number of received nominations. Each participant is represented by 21 data
12 points, once for each day.

13

14 **Figure 3: Pain homogeneity by day**

15 The black dotted line shows the mean expected homogeneity of pain between connected
16 participants, the dark grey area and the light grey area the 50% and 90% bands of expected
17 homogeneity. The red solid line shows the observed amount of pain homogeneity.

18

19 **Figure 4: Cross-sex nominations by total amount of pain experienced**

20 Number of cross-sex nominations by participants dependent on overall pain. Each
21 participant is represented by 21 data points, once for each day.

22

1 **Tables**

2 **Table 1: Results of the SAOM analysis for the co-evolution of the interaction**
 3 **network and pain**

4

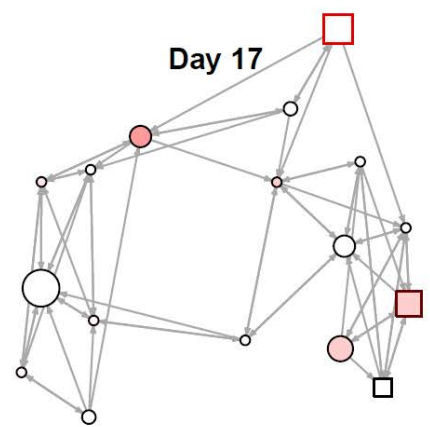
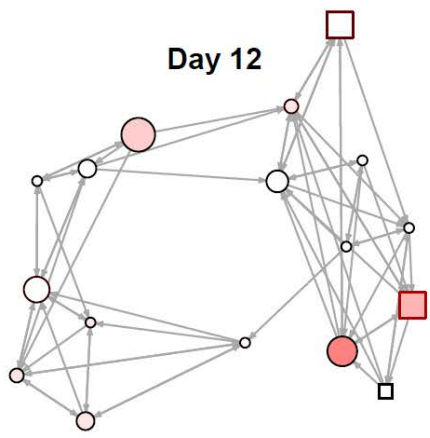
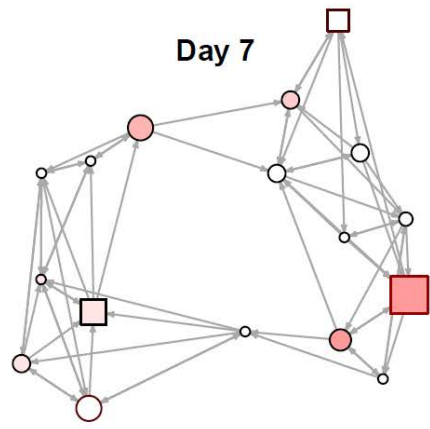
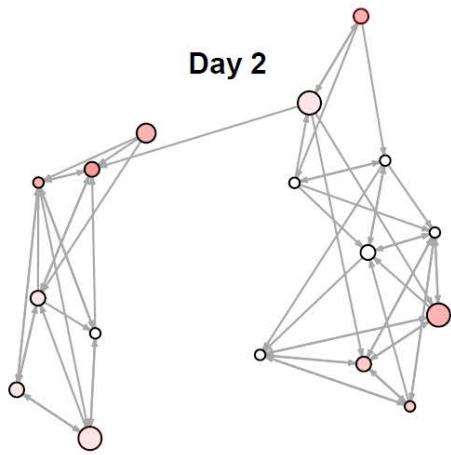
5

	Model 1			Model 2			Model 3		
Network Evolution	estimate	sig	s.e.	estimate	sig	s.e.	estimate	sig	s.e.
Outdegree (Intercept)	-2.110	***	(0.193)	-2.092	***	(0.197)	-2.193	***	(0.206)
Reciprocity	2.587	***	(0.208)	2.608	***	(0.206)	2.618	***	(0.211)
Transitivity (GWESP)	1.587	***	(0.103)	1.590	***	(0.106)	1.591	***	(0.105)
Indegree Popularity	-0.142	***	(0.032)	-0.175	***	(0.035)	-0.171	***	(0.035)
Reciprocity * Transitivity (GWESP)	-1.458	***	(0.192)	-1.478	***	(0.190)	-1.495	***	(0.192)
Sex Popularity (Girl)	0.062		(0.077)	0.187	*	(0.089)	0.111		(0.094)
Same Sex	0.369	***	(0.070)	0.380	***	(0.070)	0.467	***	(0.098)
Pain Popularity	-0.257	***	(0.072)	-0.095		(0.087)	-0.136		(0.089)
Pain Homophily	0.078		(0.062)	0.068		(0.063)	0.134		(0.070)
Pain Popularity * Male				-0.398	**	(0.131)	-0.405	*	(0.161)
Males Nominate Males in Pain							0.038		(0.148)
Males in Pain Nominate Females							-0.300	*	(0.141)
Pain Evolution									
Intercept	-2.167	***	(0.172)	-2.223	***	(0.213)	-2.182	***	(0.176)
Outdegree Activity	0.242	***	(0.027)	0.243	***	(0.027)	0.244	***	(0.026)
Effects from Sex	0.431	**	(0.135)	0.517	*	(0.234)	0.431	**	(0.134)
Pain Influence	-0.076		(0.102)	-0.034		(0.143)	-0.077		(0.105)
Influence * Females				-0.083		(0.189)			
Muscle Use (ref: cold)	0.772	***	(0.222)	0.765	***	(0.220)	0.781	***	(0.221)
Headache	-2.045	***	(0.359)	-2.059	***	(0.365)	-2.046	***	(0.358)
Rubbing and Blisters	0.267		(0.217)	0.263		(0.219)	0.273		(0.216)
Injuries	-0.377		(0.231)	-0.384		(0.228)	-0.374		(0.228)
Stomach ache	-0.858	***	(0.252)	-0.862	***	(0.254)	-0.863	***	(0.250)
Other Pain	-0.898	***	(0.259)	-0.897	***	(0.261)	-0.889	***	(0.260)

6 Levels of significance and p-values: *** <0.001; ** <0.01; * <0.05; Rate parameters for network
 7 evolution and dummies for each day omitted. Results using pain from cold as the reference
 8 category is an arbitrary choice.

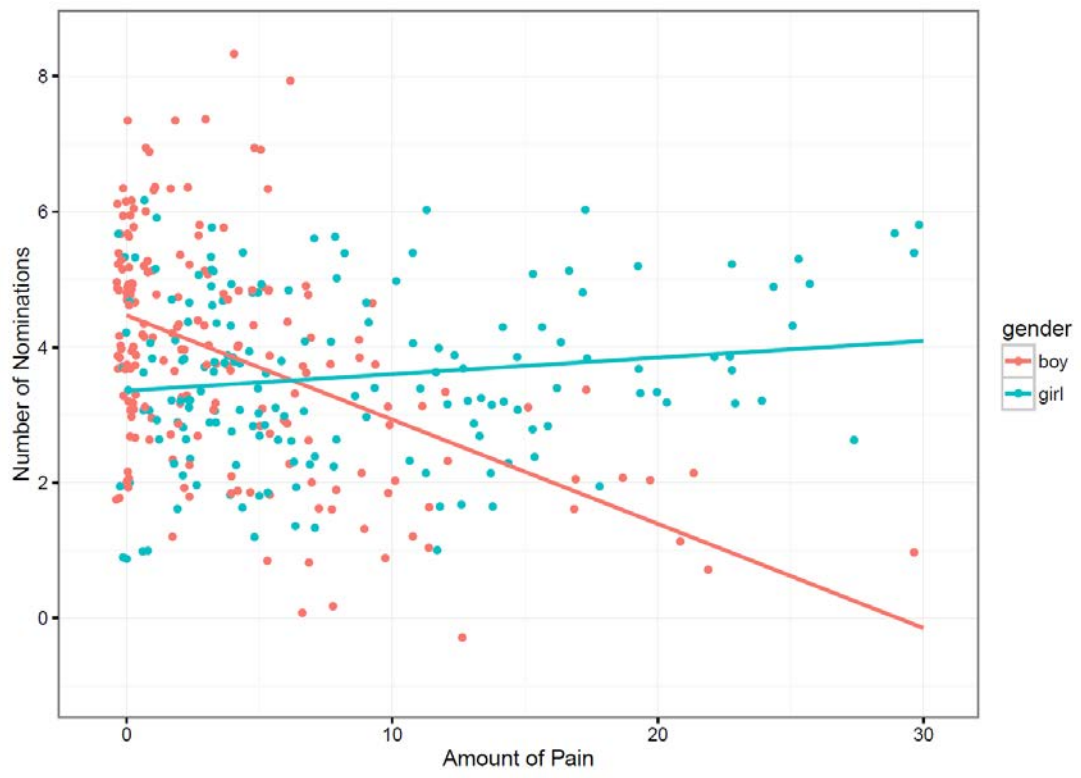
1 **Figures**

2 **Figure 1**



3

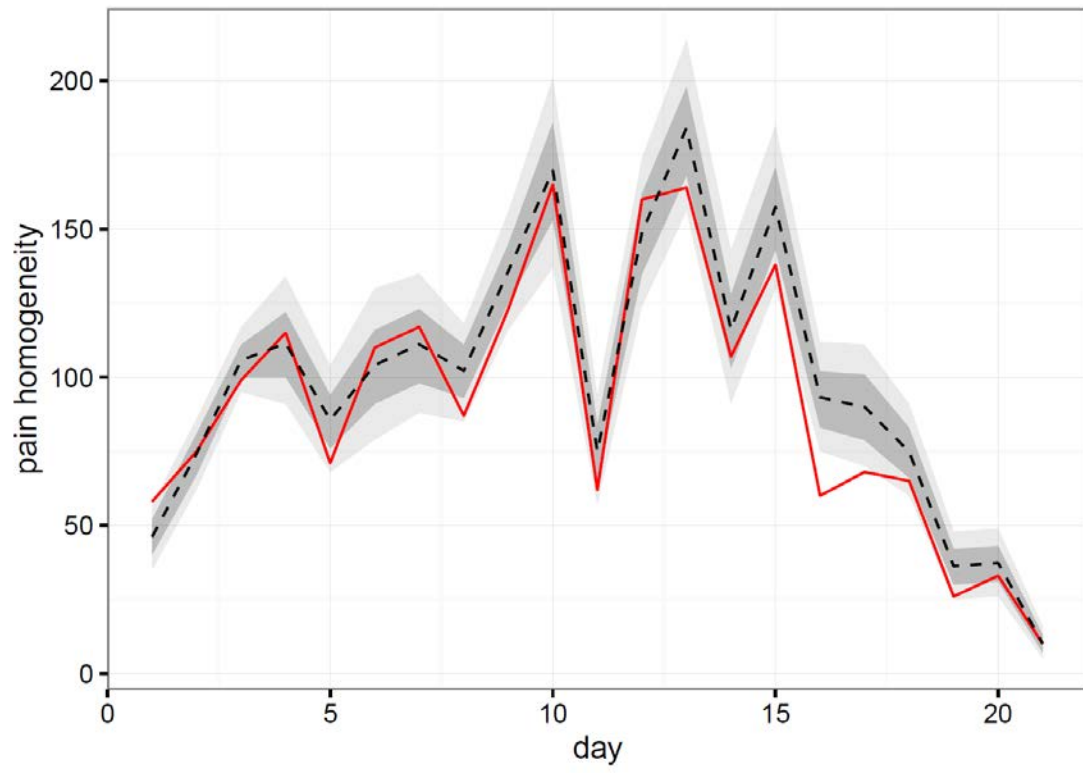
1 **Figure 2**



2

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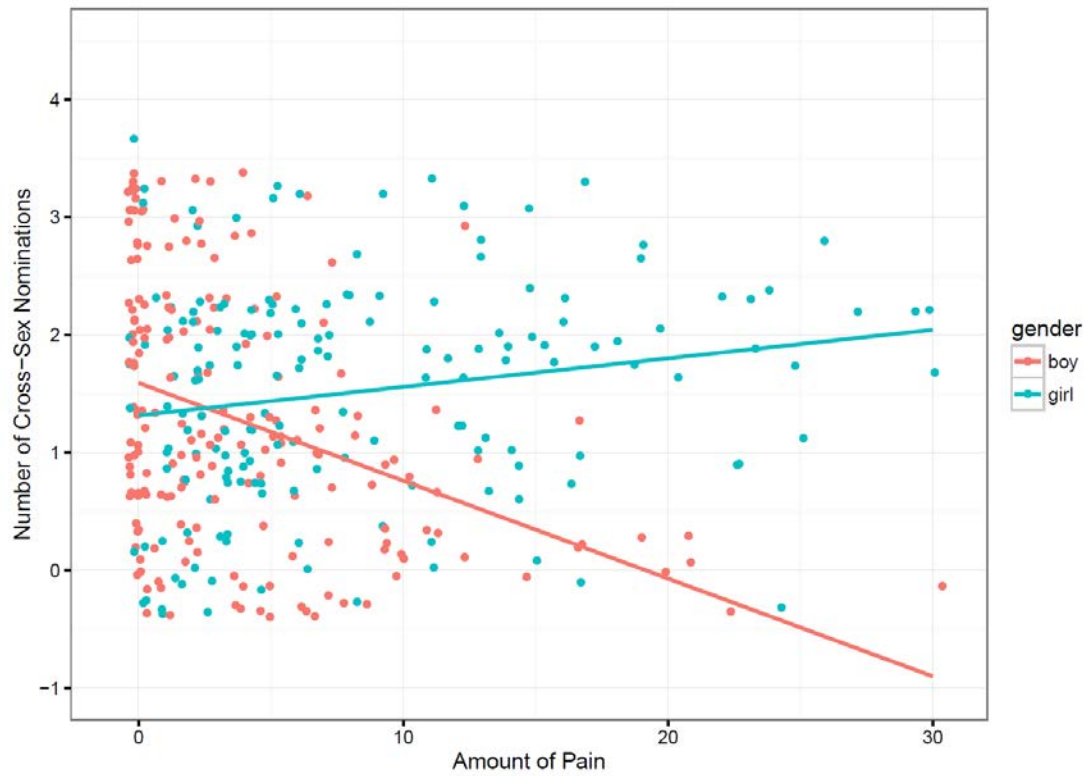
1 **Figure 3**



2

3

1 **Figure 4**



2